A comparative evaluation of coupled mixed-mode cohesive zone laws for interfacial debonding

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A COMPARATIVE EVALUATION OF COUPLED MIXED-MODE COHESIVE ZONE LAWS FOR INTERFACIAL DEBONDING

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Several coupled and uncoupled cohesive zone (CZ) laws are widely adopted in the literature to describe the mixed-mode fracture process of ductile and brittle materials and interfaces. Among the class of coupled models, CZ laws usually differ in several aspects, including the definition of the coupling parameters, the shape of the laws, the unloading paths, and the lack or presence of a potential, affecting the fracture energies in different mode mixities.

In the current literature, however, the relative performance of different models has rarely been the subject of a comparative assessment, and the consistency of the models with the physics of the interfacial mixed-mode decohesion process has remained most frequently unchecked. A well-known consistency check was performed by van den Bosch et al. [1] on the model by Xu and Needleman [2]. This led to the identification of an energy inconsistency and to the proposal of an improved version of the model. However, several other models which are frequently used in numerical applications have never been analyzed in a similar fashion. A parametric analysis on the effect of the coupling parameters on stress distributions and energy dissipation can be useful to evaluate possible physical inconsistencies of a model, such as local abnormalities in the coupled elastic or softening mechanical response of the interface, incomplete dissipation of the fracture energy during decohesion, residual load-carrying capacity in normal or tangential traction after complete failure, etc. Advantages and/or shortcomings of each cohesive model, if explicitly assessed, may also justify the adoption of one model or another for numerical implementations.

Herein we analyze the main aspects of some coupled CZ laws, which are widely used in the literature for crack propagation studies of materials under mixed-mode loading, such as: the bilinear law by Högberg [3], the bilinear law by Camanho et al. [4], the trapezoidal law by Tvergaard and Hutchinson [5], and the polynomial law by Tvergaard [6]. The coupling effect on stresses and energy dissipation is first investigated and the path-dependence of the mixed-mode debonding work of separation and failure domains is analytically evaluated.

The numerical performance of each cohesive model is then numerically assessed and compared by simulating a mixed-mode bending (MMB) test and a bi-material peel test under mixed-mode loading conditions. In the numerical implementation all the interface laws are implemented into a contact element based on the node-to-segment strategy as employed in [7] and generalized to handle cohesive forces in both the normal and tangential directions. The non-penetration condition in the normal direction under compression is enforced using the penalty method. Depending on the contact status, an automatic switching procedure is used to choose between cohesive and contact models. The main differences between the selected laws and their consistency are numerically assessed and compared with the analytical predictions. Moreover, some suggestions for improvement of the consistency issues are set forth.

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